REMARKS

Claims 7-18 are pending in this application. By this Preliminary Amendment, Applicant AMENDS the specification and the abstract of the disclosure, CANCEL claims 1-6 and ADDS new claims 7-18.

Applicant has attached hereto a Substitute Specification in order to make corrections of minor informalities contained in the originally filed specification. Applicant's undersigned representative hereby declares and states that the Substitute Specification filed concurrently herewith does not add any new matter whatsoever to the above-identified patent application. Accordingly, entry and consideration of the Substitute Specification are respectfully requested.

The changes to the specification have been made to correct minor informalities to facilitate examination of the present application.

Applicant respectfully submits that this application is in condition for allowance. Favorable consideration and prompt allowance are respectfully solicited.

Respectfully submitted,

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ELECTROMAGNETIC FIELD ANALYZER, ELECTROMAGNETIC FIELD
ANALYZING PROGRAM, AND STORAGE MEDIUM FOR RECORDING THE
PROGRAM

TECHNICALBACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to electromagnetic field

simulation technology used in developmentdeveloping and

designing of high-frequency products such as multilayer

products, giga filters, and EMI (Electro-Magnetic

Interference) elimination filters, etc.,and more particularly,

the present invention relates to an electromagnetic field

analyzer, an electromagnetic field analyzing program, and a

storage medium for recording the program in which the

simulation time can be shortenedis reduced.

Background

2. Description of the Related Art

In recent years, the development and designing of high-

frequency products have been vigorously performed aggressively

pursued, and, in order to perform an electromagnetic field

analysis of high-frequency products, electromagnetic field

simulation softwares have been widelysoftware has been

commonly used. Generally, there are many easesinstances where

a finite element method is used for electromagnetic field

analysis. In the electromagnetic field simulation using the

finite element method, since it takes a long time to solve

simultaneous linear equations, high-speed solving methods are

desired. In particular, in the field of electromagnetic field analysis, since ~~nothing except for~~ only a direct method called a Gauss' elimination method can be used, the problem of ~~taking a~~ long calculation ~~time~~ times is more serious.

However, ~~by~~ a paper (R. Hiptmair, "Multigrid ~~method~~Method for Maxwell's ~~equations~~Equations," SIAM Journal of Numerical Analysis, vol. 36, no. 1, pp. 204-225, 1999~~)~~), which is referred to herein as Non-patent document 1, and which was made public by Hiptmair in 1999, ~~it is~~ proved that a solution method called a multi-grid method can be also used in an electromagnetic field analysis and the method ~~is paid attention to as a~~ greatly ~~speeding up solution when~~ reduces the calculation time as compared ~~with~~to a direct method.

In the multi-grid method, an analysis object is divided into two classes of fine elements and coarse elements, and the solution of fine elements is ~~found by making use of~~ determined using the solution of coarse elements.

When simultaneous linear equations are calculated by ~~using~~ the Gauss' elimination method, generally the calculation time is proportional to the third power of the dimensions of a matrix. Since the size of the dimensions corresponds to the number of elements, when the number of elements ~~becomes double~~is doubled, the calculation time ~~becomes~~is 8 times as large, and, when the number of elements ~~becomes~~is 10 times as large, the calculation time ~~becomes~~is 1,000 times as large. ~~Then, when~~When the Gauss' direct method is applied to only coarse elements, an approximate solution to fine elements is obtained by using ~~a~~the solution to coarse elements, and the Gauss' elimination method is not used, the calculation time

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for fine elements can be reduced to 1/8 and 1/1000,
respectively. Since additional calculation time is added,
although the practical calculation time is not reduced ~~as~~ to
such a great extent, the calculation time ~~can be~~is always
greatly reduced ~~without fail~~.

The multi-grid method ~~is classified~~can be broken down into
two methods: a method using a nested mesh and a method using
a non-nested mesh. However, since a prolongation matrix is
incomplete as described later, ~~there is nothing except for
using a~~ the method using a nested mesh must be used.

Figs. 12A and 12B ~~are drawings for describing~~show the
division into elements using a nested mesh. Fig. 12A shows
the division into elements using a nested mesh in the case of
two-dimensional analysis where a coarse triangular element is
uniformly divided to form fine triangular elements.
Furthermore, Fig. 12B shows the division into elements using a
nested mesh in the case of three-dimensional analysis where a
coarse tetrahedral element is uniformly divided to form eight
fine tetrahedral elements. As ~~is~~ understood from Figs. 12A
and 12B, there are geometrical restrictions between coarse
elements and fine elements ~~in the case of~~when using a nested
mesh.

~~Non-~~Another prior art method is described in non-patent
document ~~1: R. Hiptmair, "~~2: D. Dibben and T. Yamada, "Non-
Nested Multigrid ~~method for Maxwell's equations," SIAM Journal
of Numerical Analysis, vol. 36, No. 1, pp. 204-225, 1999~~

~~Non-patent document 2: D. Dibben and T. Yamada, "Non-
nested multigrid and automatic mesh coarsening for high
frequency electromagnetic problems~~and Automatic Mesh

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Coarsening for High Frequency Electromagnetic Problems" IEEJ
Investigating Research Committee ~~material~~Material, SA-02-34,
pp. 71-75, 2002.

Figs. 13A and 13B ~~are drawings for describing~~describe a
first problem ~~of~~that occurs when using a nested mesh. Fig.
13A shows how a circle is divided into elements using a nested
mesh to form coarse elements. Furthermore, Fig. 13B shows how
coarse elements are divided into fine elements using a nested
mesh. As ~~is~~understood from Figs. 13A and 13B, a curved
surface cannot be correctly expressed because of the
geometrical restrictions of a nested mesh.

Furthermore, Fig. 13C shows how a circle is divided into
elements using a non-nested mesh to form fine elements. As ~~is~~
understood from Fig. 13C, since there are no geometrical
restrictions when using a non-nested mesh, a curved surface
can be correctly expressed.

Figs. 14A to 14C ~~are to~~describe a second problem ~~of~~that
occurs when using a nested mesh. Fig. 14A shows how a square
is divided into elements ~~by~~using a nested mesh to form coarse
elements. Furthermore, Fig. 14B shows how coarse elements are
divided into fine elements. As ~~is~~understood from Figs. 14A
and 14B, coarse elements cannot be partially divided into fine
elements because of the geometrical restrictions of a nested
mesh.

Furthermore, Fig. 14C shows how a square is divided into
elements ~~by~~using a non-nested mesh to form fine elements. As
~~is~~understood from Fig. 14C, coarse elements can be partially
divided into fine elements because ~~of~~there are no geometrical
restrictions when using a non-nested mesh.

Most industrial products have curved surfaces, such as ~~in~~ a circular cylinder and ~~a~~ square surfaces, and they inevitably contain partially fine portions. Accordingly, it is difficult to apply a nested mesh to industrial products. On the other hand, since there ~~is~~ are no geometrical restrictions in a non-nested mesh, fine elements can be freely formed. However, since the positional ~~relation~~relationship is not systematic, it is difficult to make the electromagnetic field of coarse elements related to the electromagnetic field of fine elements. It is a prolongation matrix to make coarse elements related to fine elements, but no precise prolongation matrix has been found. This means that a multi-grid method cannot be practically used, and accordingly, nothing can be used except for a Gauss' direct method, which ~~takes much~~ requires a lot of time, in the analysis of magnetic field.

~~Disclosure of Invention~~

~~The present invention has been done to solve the~~

SUMMARY OF THE INVENTION

To overcome the problems described above ~~problem, and it is an object~~, preferred embodiments of the present invention ~~to~~ provide an electromagnetic field analyzer, an electromagnetic field analyzing program, and a recording medium having the program recorded ~~therein~~thereon, in which the analysis of an electromagnetic field can be ~~made by using~~performed via a multi-grid method using a non-nested mesh~~.~~

~~It is another object of the present invention to provide~~, and an electromagnetic field analyzer, an electromagnetic field analyzing program, and a recording medium in which the program has been recorded, in which the time required for an

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electromagnetic field analysis is greatly reduced.

According to ~~an aspect~~a preferred embodiment of the present invention, an electromagnetic field analyzer ~~comprises~~includes dividing means for dividing form data as an analysis object into coarse elements and fine elements~~,~~, forming means for forming a matrix ~~making~~defining an electromagnetic field vector of the coarse elements divided by the dividing means related to an electromagnetic field vector of the fine elements, and calculating means for calculating an approximate solution of the electromagnetic field vector of the fine elements by applying an iteration method of simultaneous linear equations while referring to the matrix formed by the forming means.

Preferably, the forming means forms the matrix by expressing the elements of electromagnetic field vectors at the sides at a fine element using an interpolation function in the coarse elements.

More preferably, when the length of a side l_i of the fine element is $|l_i|$, an interpolation function showing the ~~relation~~relationship between the electromagnetic field at position x of the side l_i of the fine element and the electromagnetic field at a side j of the coarse element is N_j^c (x), and the tangential vector of the side l_i of the fine element is t_i, the forming means ~~(25)~~forms a matrix P_{ij} preferably by Expression (14) to be described later.

More preferably, in the ~~calculation~~calculating means, the accuracy of an approximate solution of the electromagnetic field vector of the fine elements is improved such that high-frequency components included in the approximate solution of

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the electromagnetic field vector of the fine element are removed by applying a stationary iteration method of simultaneous linear equations, such that a residual in the fine elements is mapped to a residual in the coarse elements by using the matrix formed by the forming means, such that a correction vector to the coarse elements is formed by applying a direct method or a non-stationary iteration method of simultaneous linear equations, and such that a correction vector to the fine elements is obtained by using the matrix formed by the forming means.

According to another ~~aspect~~preferred embodiment of the present invention, in a computer program to ~~cause~~control a computer to execute an electromagnetic field analyzing method for analyzing an electromagnetic field as an analysis object, the computer ~~contains~~includes a first storage ~~means for storing~~device arranged to store divided elements and a second storage ~~means for storing~~device arranged to store a matrix, and the electromagnetic field analyzing method ~~contains~~includes the steps of dividing form data as an analysis object into coarse elements and fine elements and storing the elements in the first storage ~~means~~device, forming a matrix ~~making~~defining an electromagnetic field vector of the coarse elements stored in the first storage ~~means~~device related to an electromagnetic field vector of the fine elements and storing the matrix in the second storage ~~means~~device, and calculating an approximate solution of the electromagnetic field vector of the fine elements by applying an iteration method of simultaneous linear equations while referring to the matrix stored in the second storage

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~~means~~device.

According to another ~~aspect~~preferred embodiment of the present invention, in a computer readable storage medium~~,~~ ~~being computer readable, for recording~~ having stored thereon a program to ~~cause~~control a computer to execute an electromagnetic field analyzing method for analyzing an electromagnetic field as an analyzing object, the computer ~~contains~~includes a first storage ~~means for storing~~device arranged to store divided elements and a second storage ~~means for storing~~device arranged to store a matrix, and the electromagnetic field analyzing method ~~contains~~includes the steps of dividing form data as an analysis object into coarse elements and fine elements and storing the coarse and fine elements in the first storage ~~means~~device, forming a matrix ~~making~~defining an electromagnetic field vector of the coarse elements stored in the first storage ~~means~~device related to an electromagnetic field vector of the fine elements and storing the matrix in the second storage ~~means~~device, and calculating an approximate solution of the electromagnetic field vector of the fine elements by applying an iteration method of simultaneous linear equations while referring to the matrix stored in the second storage ~~means~~device.

~~According to an aspect of the present invention, since~~

Since the forming means forms a matrix ~~making~~defining an electromagnetic field vector of coarse elements divided by the dividing means related to an electromagnetic field vector of fine elements, it ~~became~~is possible to perform an electromagnetic field analysis ~~by using~~via a multi-grid method using a non-nested mesh. Furthermore, since the calculating

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means calculates an approximate solution of the electromagnetic field vector of fine elements while referring to the matrix formed by the forming means, ~~it~~the calculating means is not required to calculate the electromagnetic field of fine elements by using a direct method~~, it became possible to largely reduce a~~-. Thus, the time ~~needed~~required for an electromagnetic field analysis is greatly reduced.

Furthermore, since the forming means forms a matrix such that an electromagnetic field vector element at a side of fine elements is expressed by using an interpolation function in coarse elements, ~~it became possible to~~ a matrix is easily ~~form a matrix~~formed.

Furthermore, in the forming means, since a matrix P_{ij} is formed preferably by Expression (14) to be described later, a matrix ~~can be~~is even more easily formed.

Furthermore, in the calculating means, an approximate solution of an electromagnetic field vector of fine elements is corrected by using a matrix formed by the forming means~~, it became possible to improve~~. Thus, the accuracy of the approximate solution of an electromagnetic field vector of fine elements is greatly improved at high speed.

~~Brief Description of the Drawings~~

Other features, elements, steps, characteristics and advantages of the present invention will become more apparent from the following detailed description of preferred embodiments thereof with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 ~~is an external appearance of~~shows an

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electromagnetic field analyzer according to ~~ana~~ a preferred

embodiment of the present invention.

Fig. 2 is a block diagram showing the construction of the

electromagnetic field analyzer according to ~~ana~~ a preferred

embodiment of the present invention.

Fig. 3 is a block diagram showing the functional structure

of the electromagnetic field analyzer.

Fig. 4 is a flow chart for describing the procedure of the

electromagnetic field analyzer.

Fig. 5A shows a microstrip line divided into large

elements.

Fig. 5B shows a microstrip line which is analyzed using

the large elements shown in Fig. 5A, and in which the elements

are subdivided based on their error estimation.

Fig. 6 shows components of an electromagnetic field

~~which~~that are in contact with the sides of a tetrahedron.

Fig. 7 shows the ~~relation~~relationship between an

electromagnetic field vector u^F in Ω^F and an electromagnetic

field vector u^c in Ω^c.

Fig. 8 shows one example of a rectangular waveguide as an

analysis object of an electromagnetic field analyzer according

to ~~ana~~ a preferred embodiment of the present invention.

Fig. 9 shows the calculation time to the number of

elements when the rectangular waveguide shown in Fig. 8 is

driven in TE10 mode of 2.45 GHz, which is compared between the

case where a related direct method is used and the case where

a method of a preferred embodiment of the present invention is

used.

Fig. 10 shows one example of a patch antenna as an analysis object of the electromagnetic field analyzer according to ~~an~~a preferred embodiment of the present invention.

Fig. 11 shows the calculation time to the number of elements when the patch antenna shown in Fig. 10 is driven at 7.0 GHz, which is compared between the case where a related direct method is used and the case where a method of the present invention is used.

Fig. 12A shows elements divided by using a nested mesh in the case of two-dimensional analysis.

Fig. 12B shows elements divided by using a nested mesh in the case of three-dimensional analysis.

Fig. 13A shows coarse elements formed such that a circle is divided into elements by using a nested mesh.

Fig. 13B shows fine elements into which coarse elements are divided by using a nested mesh.

Fig. 13C shows fine elements formed such that a circle is divided into elements by using a non-nested mesh.

Fig. 14A shows coarse elements formed such that a square is divided into elements using a nested mesh.

Fig. 14B shows fine elements into which coarse elements are divided by using a nested mesh.

Fig. 14C shows fine elements formed such that a square is divided into elements by using a non-nested mesh.

~~Reference Numerals~~

―――

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Fig. 1 ~~computer main body~~

2   display device

3   FD drive

4   FD

5   keyboard

6   mouse

7   CD-ROM device

8   CD-ROM

9   network communications device

10   CPU

11   ROM

12   RAM

13   hard disk

21   form data storage portion

22   division into element portion

23   element storage portion

24   vector/matrix forming portion

25   prolongation matrix forming portion

26   vector/matrix storage portion

27   prolongation matrix storage portion

28   approximate value calculation portion

29   approximate solution correction portion

30   electromagnetic field vector storage portion

Best Mode for Carrying Out the Invention

Fig. 1 is an external appearance of shows an electromagnetic field analyzer according to ana preferred embodiment of the present invention. The electromagnetic field analyzer containspreferably includes a computer main body 1, a display device 2, an FD (Flexible Disk) drive 3 to which an FD 4 is attached, a keyboard 5, a mouse 6, a CD-ROM

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(Compact Disk- Read Only Memory) drive 7 to which a CD-ROM 8

is attached, and a network communications device 9. An

electromagnetic field analyzing program is supplied through a

recording medium such as an FD 4, or a CD-ROM 8, ~~etc.~~or other

suitable media. An electromagnetic field analysis is

performed such that the electromagnetic field analyzing

program is executed by the computer main body 1. Furthermore,

the electromagnetic field analyzing program may be supplied to

the computer main body 1 by ~~anther~~another computer through the

network communications device 9.

Fig. 2 is a bock diagram showing the construction of the

electromagnetic field analyzer ~~of an~~according to a preferred

embodiment of the present invention. The computer main body 1

shown in Fig. ~~1 contains~~1 includes a CPU (Central Processing

Unit) 10, a ROM (Read Only Memory) 11, a RAM (Random Access

Memory) 12, and a hard disk 13. The CPU 10 ~~conducts~~performs

processing while the CPU 10 inputs and outputs data to the

display device 2, the FD drive 3, the keyboard 5, the mouse 6,

the CD-ROM device 7, the network communications device 9, the

ROM 11, the RAM 12, or the hard disk 13. The electromagnetic

field analyzing program in the FD 4 or the CD-ROM 8 is

preferably stored ~~in~~on the hard disk 13 through the FD drive 3

or the CD-ROM drive 7. The electromagnetic field analysis is

performed such that the CPU 10 properly loads the

electromagnetic field analyzing program from the hard disk 13

in the RAM 12 and executes the program.

Fig. 3 is a block diagram showing the functional structure

of the electromagnetic field analyzer according to ~~an~~a

preferred embodiment of the present invention. The

electromagnetic field analyzer ~~contains~~includes a form data

storage portion 21 for storing form data as an analysis object,

a division-into-element portion 22 for dividing the form data,

such that the size of elements is changed, an element storage

portion 23 for storing the elements divided by the division-

into-element portion 22, a vector/matrix forming portion 24

for forming a vector and matrix in simultaneous linear

equations, a prolongation matrix forming portion 25 for

forming a prolongation matrix, a vector/matrix storage portion

26 for storing the vector and matrix formed by the

vector/matrix forming portion 24, a prolongation matrix

storage portion 27 for storing the prolongation matrix formed

by the prolongation matrix forming portion 25, an approximate

value calculation portion 28 for calculating an approximate

value of an electromagnetic field vector, an approximate

solution correction portion 29 for correcting the approximate

solution calculated by the approximate value calculation

portion 28, and an electromagnetic-field vector storage

portion 30 for storing, as an electromagnetic field vector,

the approximate solution after having been corrected by the

approximate solution correction portion 29.

Moreover, the form data storage portion 21, the element

storage portion 23, the vector/matrix storage portion 26, the

prolongation matrix storage portion 27, and the

electromagnetic field vector storage portion 30 are provided

in a fixed area in the RAM 12 or on the hard disk 13 shown in

Fig. 2. Furthermore, the ~~function~~functions of the division-

into-element portion 22, the vector/matrix forming portion 24,

the prolongation matrix forming portion 25, the approximate

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value calculation portion 28, and the approximate solution

correction portion 29 ~~is realized~~are arranged such that the

CPU 10 shown in Fig. 2 executes the electromagnetic field

analyzing program loaded into the RAM 12.

Fig. 4 is a flow chart for describing the procedure of the

electromagnetic field analyzer according to ~~an~~a preferred

embodiment of the present invention. First, the division-

into-element portion 22 reads form data as an analysis object

stored in the form data storage portion 21, divides the form

data into elements, and ~~preserves~~stores the divided elements

in the element storage portion 23 (S11). The division-into-

element portion 22 divides the form data into triangular or

quadrangular elements in the case of two-dimensional analysis,

and divides the form data into tetrahedral, triangle-pole-

shaped, or square-pole-shaped elements in the case of three-

dimensional analysis.

The division-into-element portion 22 divides the form data

while changing the size of the elements. In order to make the

description simple, ~~here~~ elements of two different sizes are

formed and it is assumed that a set of larger (coarse)

elements is made Ω^c and a set of smaller (fine) elements is

made Ω^F. Moreover, a superscript of c represents coarse, and a

superscription of F represents fine.

The sets of Ω^c and Ω^F may be independently formed,

~~but~~however, when the set of Ω^c is first formed and then the set

of Ω^F is formed by subdividing the elements, the processing

time is ~~shortened.~~reduced. Regarding the method of

subdivision, there ~~are~~is a method for subdividing elements

which are larger in volume and a method for analyzing elements

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by using Ω^c and subdividing elements having a large error.
Either of them may be used, ~~but~~however, the method in which
error is evaluated has ~~a~~ better calculation accuracy.
Moreover, regarding the method for evaluating error, Reference
Document No. 1 (Norio Kamiya et al., ~~"computer and~~
~~application's monk, special edition/error estimation in~~
~~software and adaptive element," No.~~"Computer and Application's
Monk, Special Edition/Error Estimation in Software and
Adaptive Element," No. 42, CORONA PUBLISHING CO., 1993~~)) can~~)
may be referred to.

Figs. 5A and 5B show examples of division into elements in
a microstrip line. In Fig. 5A, the microstrip line is divided
into larger elements. Furthermore, in Fig. 5B, an analysis is
performed by using the larger elements in Fig. 5A and the
elements are subdivided based on their error estimation.
Since the electromagnetic field is concentrated at the edge of
an electrode, the portion is subdivided into smaller elements.

Next, the vector/matrix forming portion 24 reads the sets
Ω^c and Ω^F stored in the element storage portion 23,
discretization of the sets takes place using their elements
such that a finite element method is applied to a Maxwell
equation, and a matrix and column vector in simultaneous
linear equations are formed (S12). Here, the Maxwell equation
as an object is represented by the following expression~~-~~s:

~~Expression 1~~

$$\nabla \times H = (\hat{\sigma} + j\omega\hat{\varepsilon})E \qquad \cdots(1)$$
$$\nabla \times E = -j\omega\hat{\mu}H \qquad \cdots(2)$$

~~Here,~~ Expressions 1 and 2

$$\nabla \times H = (\hat{\sigma} + j\omega\hat{\varepsilon})E \qquad \cdots(1)$$
$$\nabla \times E = -j\omega\hat{\mu}H \qquad \cdots(2)$$

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Where E: electric field, H: magnetic field, ε: dielectric constant, μ: permeability, σ: conductivity, ω: angular frequency, ∇: differential operator (∂/∂x, ∂/∂y, ∂/∂z), X: outer product, j: imaginary number

From these expressions, the following differential equation ~~can be~~is obtained~~.~~:

Expression ~~2~~3

$$\nabla \times \hat{p}\nabla \times u - \omega^2 \hat{q}u = 0 \qquad \cdots (3)$$

u represents an electric field, magnetic field, etc., and $\hat{p}$ and $\hat{q}$ represent characteristic values of dielectric constant and permeability. For example, when Expression (3) is obtained by substituting Expression (2) into Expression (1) and eliminating H, u represents an electric field, $\hat{p}$ represent the reciprocal of a permeability, and $\hat{q}$ represents a dielectric constant.

When a finite element method is applied to an element V_k formed in the ~~above~~-former process described above, the following expression ~~can be~~is obtained~~.~~:

~~Expression 3~~

$$\int_{V_k} (\nabla \times N_{ki}) \hat{p}(\nabla \times u) dV - \omega^2 \int_{V_k} N_{ki} \hat{q}u dV = \int_{\partial V_k} (N_{ki} \times \hat{p}\nabla \times u) \cdot n dS$$

$$\cdots (4)$$

~~Here, ∂V_k represents the surface of V_k and n represents an outward normal unit vector. N_ki represents an interpolation function (also called a shape function, insertion function, basis function, etc.) When tetrahedral elements and linear equations are used, the interpolation function is given by the following expression.~~

Expression 4

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$$\int_{V_k} (\nabla \times N_{ki}) \hat{p} (\nabla \times u) dV - \omega^2 \int_{V_k} N_{ki} \hat{q} u dV = \int_{\partial V_k} (N_{ki} \times \hat{p} \nabla \times u) \cdot n dS$$

$$\cdots (4)$$

Here, ∂V_k represents the surface of V_k and n represents an outward normal unit vector. N_{ki} represents an interpolation function (also called a shape function, insertion function, or basis function). When tetrahedral elements and linear equations are used, the interpolation function is given by the following expression:

Expression 5

$$N_{k1} = |l_1| (L_2 \nabla L_3 - L_3 \nabla L_2)$$
$$N_{k2} = |l_2| (L_3 \nabla L_1 - L_1 \nabla L_3)$$
$$N_{k3} = |l_3| (L_1 \nabla L_2 - L_2 \nabla L_1)$$
$$N_{k4} = |l_4| (L_1 \nabla L_4 - L_4 \nabla L_1) \qquad \cdots (5)$$
$$N_{k5} = |l_5| (L_2 \nabla L_4 - L_4 \nabla L_2)$$
$$N_{k6} = |l_6| (L_3 \nabla L_4 - L_4 \nabla L_3)$$

Here, L_1 to L_4 represent a volume coordinate system and $|l_1|$ to $|l_6|$ represent the length of a side l_i. Moreover, regarding the detail of the volume coordinate system, Reference Document 2 (T. Itoh, G. Pelosi and P. P. Silvester, "Finite Element Software for Microwave Engineering," John Wiley & Sons, pp. 101-125, 1996) ~~can~~may be referred to.

Fig. 6 shows components of an electromagnetic field u ~~which~~that are in contact with the sides of a tetrahedron. The components of the electromagnetic field u are ~~disposed~~ arranged so as to be disposed along the six sides, and ~~they~~ are represented by u_1 to u_6. The electromagnetic field at

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point x inside the element V_k ~~can be~~is represented by the following expression using Expression (~~5~~6) and the six components of an electromagnetic field~~.~~:

~~Expression 5~~

$$\cancel{u(x)=\sum_{i=1}^{6} N_{ki}(x)u_{ki}} \quad \cancel{\cdots(6)}$$

~~When Expression (6) is substituted into Expression (4) and applied to all the elements of Ω^F, the following simultaneous linear equations can be obtained.~~

Expression 6

$$u(x)=\sum_{i=1}^{6} N_{ki}(x)u_{ki} \qquad \cdots(6)$$

~~Here, u^F is vectors which are electromagnetic fields disposed at the sides, and the dimensions are equal to the number of the sides as a general rule. The components of a matrix A^F are formed by the following expression.~~

When Expression (6) is substituted into Expression (4) and applied to all of the elements of Ω^F, the following simultaneous linear equations are obtained:

Expression 7

$$A^F u^F = b^F \qquad \cdots(7)$$

Here, u^F represents vectors which are electromagnetic fields disposed at the sides, and the dimensions are equal to the number of the sides as a general rule. The components of a matrix A^F are formed by the following expression:

Expression 8

$$\sum_{k=1}^{N^F} \sum_{i=1}^{6} \sum_{j=1}^{6} [\int_{V_k} (\nabla \times N_{ki})\hat{p}(\nabla \times N_{kj})dV - \omega^2 \int_{V_k} N_{ki}\hat{q}N_{kj}dV] \qquad \cdots(8)$$

Furthermore, a vector b^F is formed by the following

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expression.

Expression ~~8~~9

$$\sum_{k=1}^{N^F} \sum_{i=1}^{6} \sum_{j=1}^{6} \int_{\partial V_k} (N_{ki} \times \hat{p}\nabla \times N_{kj}) \cdot n dS \qquad \cdots (9)$$

Here, N^F is the number of elements in Ω^F.

The vector/matrix forming portion 24 also forms a matrix A^C corresponding to Ω^C ~~in~~via the same procedure and preserves A^F, b^F, and A^C in the vector/matrix storage portion 26. When u^F is ~~found~~determined by calculating simultaneous linear equations in Expression (7), the electromagnetic field distribution can be calculated using Expression (6) to ~~result~~ ~~in~~produce the solutions of Maxwell equations in Expressions (1) and (2).

Next, the prolongation matrix forming portion 25 reads elements Ω^F and Ω^C formed in the former process from the element storage portion 23 and, based on the geometric information, the prolongation matrix forming portion 25 forms a prolongation matrix P which ~~makes~~relates the electromagnetic field vector u^F in Ω^F ~~related~~ to the electromagnetic field vector u^C in Ω^C (S13). When the prolongation matrix is used, as shown in the following expression~~s~~, one vector can ~~make~~be used to determine the other vector ~~determined.~~:

~~Expression 9~~

Expressions 10 and 11

$$u^F = Pu^C \qquad \cdots (10)$$
$$u^C = P^t u^F \qquad \cdots (11)$$

Here, t means a transposed matrix.

Fig. 7 shows the ~~relation~~relationship between an

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electromagnetic field vector u^F in Ω^F and an electromagnetic

field vector u^C in Ω^C.   The j component u$_j$^{C} of the column vector

u^C is disposed at the side of an element of Ω^C and the

electromagnetic field u(x) at the position x in Ω^F can be

represented using an interpolation function N^C in Ω^C :

Expression 12

$$u(x) = \sum_j N_j^C(x) u_j^C \qquad \cdots (12)$$

The i component u$_i$^{F} of u^F is an average value of an

electromagnetic field at the side l$_i$ where the i component u$_i$^{F}

is disposed.   That is, the i component u$_i$^{F} of u^F is represented

by the following expression:

Expression 13

$$u_i^F = \frac{1}{|l_i|} \int_{l_i} u(x) \cdot t_i dl \qquad \cdots (13)$$

Here, t$_i$ represents a tangential unit vector of the side

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l_i. When Expression (12) is substituted for Expression (13) and compared with Expression (10), the ij component P_{ij} of a prolongation matrix P is given by the following expression.

Expression 14

$$P_{ij} = \frac{1}{|l_i|} \int_{l_i} N_j^C(x) \cdot t_i \, dl \qquad \cdots (14)$$

The prolongation matrix forming portion 25 forms a prolongation matrix using Expression (14) and preserves the prolongation matrix in the prolongation matrix storage portion 27.

Next, the approximate value calculation portion 28 sets an approximate initial value v^F to u^F in order to calculate the electromagnetic field vector v^F using simultaneous linear equations according to a multi-grid method (S14). The initial value v^F may be zero. Moreover, the ~~detail~~details of the calculation of the simultaneous linear equations according to the multi-grid method ~~can~~may be referred to in Reference Document 3 (W. Briggs, V. Henson and S. McCormick, "A Multigrid Tutorial," SIAM).

Next, the approximate value calculation portion 28 removes high-frequency components of error contained in v^F by applying a stationary iteration method of simultaneous linear equations, such as the Jacob method, the Gauss-Seidel method, or the SOR method, ~~etc.,~~ to Expression (7) (S15). Moreover, the ~~detail~~details of the iteration method can be referred to in Reference Document 4 (Satomi Hasegawa, Hidehiko Hasegawa, Kiyoji Fujino, "Iteration Method Templates", Asakura ~~shoten~~Shoten, 1996).

Next, the approximate value calculation portion 28 maps a residual r^F in Ω^F to a residual r^C in Ω^C by using the following

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~~expression~~expressions in order to remove low-frequency
components (S16).

~~Expression 13~~

Expressions 15 and 16

$$r^F = b^F - A^F v^F \qquad \cdots (15)$$
$$r^C = P^t r^F \qquad \cdots (16)$$

Next, the approximate value calculation portion 28
~~finds~~determines solutions of simultaneous linear equations in
the following expression (17) and calculates a correction
vector e^c (S17~~.~~):

Expression ~~14~~17

$$A^C e^C = r^C \qquad \cdots (17)$$

In Expression (17), although a non-stationary iteration
method, such as a direct method according to the Gauss
elimination method, a CG method~~,~~ or a GMRES method~~, etc.,~~ is
preferably used, since Expression (17) is a small matrix
~~when~~as compared ~~with~~to Expression (7), the calculation can be
performed in a short time. Moreover, the ~~detail~~details of the
iteration method can be referred to in the above-mentioned
document 4.

Next, the approximate solution correction portion 29
improves the accuracy of the approximate solution by returning
the correction vector of Ω^C to the correction vector of Ω^F by
using the following Expressions (18) and (19) at (S18~~.~~):

Expression ~~15~~18 and 19

$$e^F = P e^C \qquad \cdots (18)$$
$$v^F = v^F + e^F \qquad \cdots (19)$$

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The approximate solution correction portion 29 makes high-frequency components attenuated by applying smoothing shown in step 15 a couple of times to the approximate solution (S19).

Although the above processing in step S15 to S19 is the basic algorithm of a multi-grid method, since there are cases where the convergence is relatively slow, the convergence is ~~quickened by~~ accelerated by using another iteration method for simultaneous linear equations together as required (S20). ~~Concretely~~Specifically, the above-described processing is used as a pretreatment for a non-stationary iteration method, such as a CG method, a GMRES method, or a GCR method, ~~etc.,~~ or the processing is accelerated by a residual cutting method, etc. Moreover, the ~~detail~~details of the residual cutting method can be referred to ~~document~~in Reference Document 5 (Kikuchi et al., JSME International Journal, 62-604, Series B p. 4076, December 1996~~-12~~).

Next, the approximate solution correction portion 29 evaluates the residual of Expression (15) in step (S21). When the residual is large (S21 is no), since the electromagnetic field vector does not converge, the process ~~goes back~~returns to step S15 and the following processing is repeated. Furthermore, when the residual ~~is~~has a sufficiently small value (S21 is yes), it is ~~understood~~determined that the electromagnetic field vector converges, and the approximate solution v^F is stored in the electromagnetic field vector storage portion 30 (S22) and the processing is finished.

Fig. 8 shows one example of a rectangular waveguide as an analysis object of an electromagnetic field analyzer according to ~~an~~a preferred embodiment of the present invention. The

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dimensions of this rectangular waveguide ~~is~~are as shown in Fig.
8 and the inside is filled with air. The electromagnetic
field analysis is performed using tetrahedral primary elements.

In Fig. 9, the calculation time to the number of elements
when the rectangular waveguide shown in Fig. 8 is driven in
TE10 mode of 2.45 GHz is compared between the case where a
related direct method is used and the case where a method ~~of~~
according to the present invention is used. As ~~is~~ understood
from Fig. 9, when the number of elements increases, the effect
of the case where an electromagnetic field analyzer
~~of~~according to the present preferred embodiment is used is
~~eminent~~more pronounced and, when the number of elements is
206,266, the speed of the processing is about 17 times ~~as high~~
~~as when compared with~~greater than that of the related direct
method.

Fig. 10 shows one example of a patch antenna as an
analysis object of the electromagnetic field analyzer
according to ~~an~~a preferred embodiment of the present invention.
The dimensions of the patch antenna are ~~as~~ shown in Fig. 10,
and the patch antenna is ~~formed~~disposed on a dielectric
substrate having a thickness of about 0.794 mm and a
dielectric constant of about 2.2. The electromagnetic field
analysis is performed by using primary tetrahedral elements.

In Fig. 11, the calculation time to the number of elements
when the patch antenna shown in Fig. 10 is driven at 7.0 GHz
is compared between the case where a related direct method is
used and the case where a method according to a preferred
embodiment of the present invention is used. As is understood
from Fig. 11, when the number of elements increases, the

effect of the case where an electromagnetic field analyzer of
the present preferred embodiment is used is ~~eminent~~pronounced
and, when the number of elements is 88,445, the speed of the
processing is about 15 times ~~as high as when compared with the~~
than that of the related direct method.

As described above, according to the electromagnetic field
analyzer of the present preferred embodiment, since a
prolongation matrix P ~~making~~defining the electromagnetic field
vector u^F in Ω^F related to the electromagnetic field vector u^C
in Ω^C is formed and an electromagnetic field vector is
calculated by using this prolongation matrix, it ~~became~~is
possible to perform an electromagnetic field analysis by using
a multi-grid method using a non-nested ~~mech~~mesh.

Furthermore, since it ~~became~~is possible to perform an
electromagnetic field analysis by using a multi-grid method
using a non-nested mesh, the time required for analysis ~~can be~~
is greatly reduced ~~when~~as compared ~~with~~to an electromagnetic
field analysis using a direct method.

~~The embodiments described this time are exemplification in~~
~~all aspects and not restrictive. The scope of the present~~
~~invention is not shown by the above description, but shown by~~
~~the scope of the claims, and the range equivalent to the scope~~
~~of the claims and all modifications within the scope of the~~
~~claims are to be included.~~

— While the present invention has been described with respect
to preferred embodiments, it will be apparent to those skilled
in the art that the disclosed invention may be modified in
numerous ways and may assume many embodiments other than those
specifically set out and described above. Accordingly, it is

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intended by the appended claims to cover all modifications of the present invention that fall within the true spirit and scope of the invention.